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Compilers:

Jerry R. Barrow, Jornada Experimental Range, Agricultural Research Service, U.S. Department of Agriculture, Las Cruces, NM.

E. Durant McArthur, Shrubland Biology and Restoration Research Work Unit, Shrub Sciences Laboratory, Intermountain Research Station, U.S. Department of Agriculture, Forest Service, Provo, UT.

Ronald E. Sosebee, Department of Range and Wildlife Management, Texas Tech University, Lubbock, TX.

Robin J. Tausch, Pinyon-Juniper Research Work Unit, Intermountain Research Station, U.S. Department of Agriculture, Forest Service, Reno, NV.

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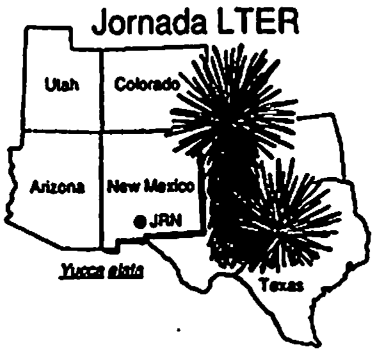

Time Series Analysis of Data for Raingauge Networks in the Southwest

M. H. Nichols
L. J. Lane
R. Gibbons

Abstract—The ability to evaluate shrubland ecosystem dynamics in a changing environment requires a historical perspective and quantitative analysis of one of the primary ecosystem inputs, precipitation. Historical time series of precipitation data collected from 25 raingauges on the USDA Jornada Experimental Range since as early as 1915 are examined. Time series analyses are conducted to test for trends, autocorrelation, and periodicities in the data and establish an association between mean annual precipitation and time. These results are compared with precipitation data from the Walnut Gulch Experimental Watershed and records from 25 raingauges on the Santa Rita Experimental Range in Southeastern Arizona. Because segments of the historic record can reveal increasing annual precipitation, decreasing annual precipitation, or no trend in annual precipitation, caution must be exercised in attempting to assign either natural variations in weather and climate or rangeland use and management practices as the cause of changes in vegetation over time.

Research conducted on experimental ranges and watersheds such as the Jornada Experimental Range near Las Cruces, New Mexico, the Santa Rita Experimental Range near Tucson, Arizona, and more recently the Walnut Gulch Experimental Watershed near Tombstone, Arizona to address management of arid and semiarid rangelands in the southwestern US has resulted in extensive multidisciplinary databases. During the past century changes in vegetation have been documented at all three sites. These changes may be a response of desert vegetation communities to gradual changes in climate and seasonal precipitation patterns, or changes associated with land use and management. The ability to evaluate shrubland ecosystem dynamics in a changing environment requires a historical perspective and quantitative analysis of one of the primary ecosystem inputs, precipitation.

The purpose of this paper is to describe temporal changes in precipitation measured over raingauge networks at rangelands sites in the Chihuahuan Desert and the Sonoran Desert, and at a site located in the transition zone between the two deserts.

Site Descriptions

Figure 1 shows the locations of three experimental areas discussed in this paper.

Walnut Gulch Experimental Watershed, Tombstone, Arizona

An extensive hydrologic database has been developed on the 150 sq km Walnut Gulch Experimental Watershed in Southeastern Arizona. The watershed is located in the transition zone between the Sonoran and Chihuahuan Deserts and is representative of approximately 60 million hectares of brush and grass covered rangeland found throughout the semiarid southwest (Renard and others 1993). Although initially instrumented to address water supply issues, the watershed has been the site of multidisciplinary research and database development since the late 1950's. Precipitation, runoff, sediment, topographic, channel networks, vegetation, soils, and landuse data have been collected. A recording raingauge network was initiated in 1954 to quantify and characterize precipitation on the Walnut Gulch Watershed. Continuous precipitation data currently are recorded by 85, 24 hour time scale, raingauges.

Vegetation on the watershed has changed from a grassland to a watershed that is dominated by shrubs on the lower ⅔ of the watershed during the past century (Hastings and Turner 1965). Shrub canopy ranges from 30-40% and grass canopy cover ranges from 10-80%. Shrub species include creosote bush (*Larrea tridentata*), whitethorn (*Acacia constricta*), tarbush (*Flourensia cernua*), snakeweed (*Xanthocephalum sarothrae*), and burroweed (*Isocoma tenuisecta*). Grasses include black grama (*Bouteloua eriopoda*), blue grama (*Bouteloua gracilis*), sideoats grama (*Bouteloua curtipendula*), bush muhly (*Muhlenbergia porteri*), and Lehmann lovegrass (*Eragrostis lehmanniana*).

Jornada Experimental Range near Las Cruces, New Mexico

The 800 sq km Jornada Experimental Range (JER) is a site for research to determine the processes resulting in desertification of semiarid grasslands and associated changes in ecosystem properties. The Jornada Experimental Range is located on the northern edge of the Chihuahuan Desert. The Chihuahuan Desert is separated from the Sonoran Desert by a high plain at the lower end of the Rocky Mountains that separates southeastern Arizona and southwestern New Mexico.

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The authors are Hydraulic Engineer and Research Leader, Southwest Watershed Research Center, Tucson, Arizona, and Hydrologist (retired), Jornada Experimental Range, Las Cruces, New Mexico, respectively.

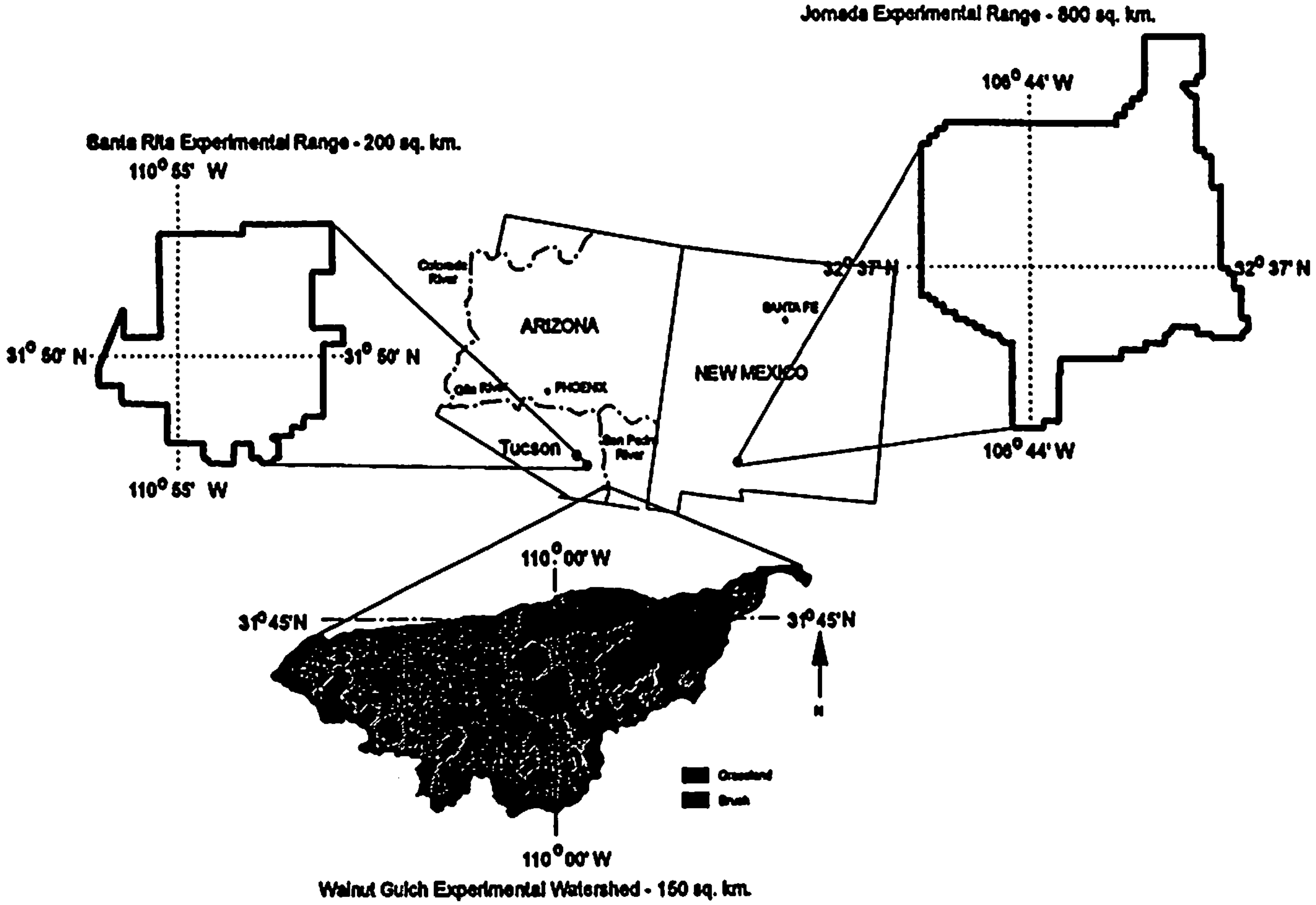


Figure 1—Location map—Santa Rita Experimental Range, Jornada Experimental Range, and Walnut Gulch Experimental Watershed.

Major grasses on the JER include black grama (*Bouteloua eriopoda*), mesa dropseed (*Sporobolus flexuosus*), and red threeawn (*Aristida purpurea* var. *longiseta*). Shrubs include honey mesquite (*Prosopis glandulosa* var. *glandulosa*), four-wing saltbush (*Atriplex canescens*), soaptree yucca (*Yucca elata*), and snakeweed. Brush invasion on the range has converted much of the grass covered range to shrub covered range (Buffington and Herbel, 1965). Precipitation data have been collected using weighing bucket raingauges since 1915 at the JER headquarters. Additional data collection for shorter periods has taken place at other locations on the JER.

Santa Rita Experimental Range near Tucson, Arizona

Research began on the 200 sq km Santa Rita Experimental Range (SRER) in 1903 to investigate the management of semiarid rangelands. The range is currently managed by the University of Arizona and is used for ecological and rangeland research. The SRER is representative of about 8 million hectares of semi-desert grass-shrub ecosystems in southern Arizona, New Mexico, and Texas (Martin and Cable 1975).

Monthly precipitation data have been collected since 1923 from weighing bucket gauges. A total of 25 annual precipitation records were analyzed, including 11 records for the time period 1923-1991.

Methods

Time Series Analysis

Linear trend analyses are conducted to test and quantify long term changes in annual precipitation with time. For each gauge annual precipitation totals were regressed against time using the simple linear regression model. Using this model, a significant trend is represented by a statistically significant regression slope at the 95% confidence level, i.e. the P-value for the slope is <0.05.

As previously reported, data from 6 Walnut Gulch raingauges with continuous 35 year records were examined for linear trends (Nichols and others 1993). A total of 25 JER continuous records with time periods ranging from 21 to 76 years (table 1), and 25 continuous records from SRER with time periods from 20 to 69 years were examined for linear trends (table 2). The slope and corresponding P-values of the linear trend are shown in tables 1 and 2 for each JER and SRER record examined. The P-value indicates the smallest value of a such that the $(1-\alpha)$ confidence interval for the slope does not include 0. Thus, the slope is significant at all confidence levels less than $(1-\alpha)$.

Autocorrelation analyses are conducted to examine seasonal and stochastic components of the time series. The autocorrelation coefficient r_k of a time series is the serial

Table 1—Summary of Jornada Experimental Range Raingauge precipitation and linear trend analysis.

Gauge name	Period of record	Mean ppt (mm/yr)	Variance (mm/yr)	Linear trend	
				Slope	P value
Headquarters	1915-1990	241.1	283.6	0.813	.068
West Well	1918-1991	225.1	282.9	0.406	.366
Red Lake	1918-1991	207.7	321.7	1.219	.013*
Dona Anna	1926-1990	236.2	270.3	1.092	.046*
Middle Well	1926-1990	223.0	356.4	0.559	.385
Road Tank	1926-1990	239.2	333.5	0.914	.132
Stuart	1926-1990	255.5	336.7	1.016	.100
Yucca	1926-1990	224.9	241.6	0.432	.421
Aristida	1927-1990	216.0	278.0	0.991	.081
Brown Tank	1927-1990	222.8	231.6	0.406	.429
New Well	1927-1990	270.4	317.8	0.864	.157
Rabbit	1927-1990	235.8	304.9	1.524	.010*
Restoration	1934-1990	227.1	323.3	2.083	.003*
Co-op Well	1937-1990	210.8	212.8	0.914	.160
Ash Canyon	1937-1976	321.0	390.1	0.533	.695
Mesquite	1937-1990	211.3	278.6	1.956	.007*
Taylor Well	1937-1990	227.3	236.4	1.499	.025*
Antelope	1938-1990	221.8	351.4	2.134	.010*
Parker	1942-1990	228.9	274.5	3.404	.001*
Excl A	1959-1990	243.5	171.4	1.727	.176
Excl B	1959-1989	226.3	205.9	1.854	.209
NE Excl	1959-1990	237.5	208.9	2.896	.036*
BER	1961-1990	232.2	150.8	0.686	.603
Past 2	1965-1990	244.7	271.6	3.150	.150
IBP	1970-1990	226.6	200.1	1.321	.622

*Linear trend with time in years significant at the 95% confidence level.

Table 2—Summary of Santa Rita Experimental Range precipitation and linear trend analysis.

Gauge name	Period of record	Mean ppt (mm/yr)	Variance (mm/yr)	Linear trend	
				Slope	P value
Florida	1923-1991	542.6	884.7	2.057	.021*
Box	1923-1991	383.8	502.9	1.753	.009*
Desert Station	1923-1991	312.9	353.8	1.245	.028*
Eriopoda	1923-1991	364.0	385.5	1.499	.011*
Forest	1923-1991	448.6	658.5	0.762	.328
Huerfano	1923-1991	371.7	453.9	1.245	.047*
Muhlenbergia	1923-1991	341.5	363.4	1.524	.007*
NW	1923-1991	290.6	298.4	1.651	.001*
Parker	1923-1991	436.7	572.7	0.483	.507
Road	1923-1991	373.6	395.0	0.889	.143
Whitehouse	1923-1991	417.8	555.2	0.737	.316
130	1939-1982	360.5	273.9	2.108	.032*
164	1940-1991	309.8	321.2	0.686	.410
205	1947-1982	344.4	310.8	3.556	.011*
41	1972-1991	419.0	735.3	5.994	.270
45	1937-1991	369.2	368.4	2.286	.004*
Amado	1967-1991	330.1	456.3	3.150	.301
Desert Grass	1933-1991	103.4	413.9	1.245	.112
Desert Rim	1935-1991	318.8	309.6	1.016	.182
Gravelly Ridge	1932-1991	321.3	336.2	0.686	.318
Limestone	1965-1991	363.2	326.2	2.286	.325
McGibbon	1947-1991	486.1	743.1	4.699	.002*
Pa 11A	1971-1982	334.1	254.3	5.740	.420
PAS 21	1971-1991	408.9	480.2	6.248	.119
PAS 3	1971-1991	304.9	358.1	2.845	.421

*Linear trend with time in years significant at the 95% confidence level.

correlation coefficient of the first N-k years of the series with the last N-k years, and the autocorrelation function is defined by $r(k) = r_k$. Autocorrelation coefficients are considered significant if they lie outside the 95% confidence interval for the autocorrelation coefficients of a random time series which is given by

$$((\pm 1.96 * \sqrt{(N-k-1)})-1) / N-k$$

It should be noted, however, that even for a random time series it is expected that 1 in 20 autocorrelation coefficients will appear significant at the 95% confidence level. The seasonal (periodic), stochastic, or random components of a time series common in hydrologic processes are revealed by the presence or absence of characteristic significant contribution to the autocorrelation function (each has a particular shape). For each gauge the autocorrelation function of the time series of annual values was computed and plotted together with the 95% confidence bands.

Spectral density analyses are conducted to compliment autocorrelation analysis. The spectral density function is defined as the Fourier cosine transform of the autocorrelation function. It is useful for detecting periodicities which are not multiples of the fundamental frequency (fundamental frequency is 1 year for our analyses). For an interval in the frequency domain the relative area under the spectral density curve is a measure of the amount of the variation of the series accounted for by frequencies in that interval. Thus, broad peaks in the spectral density function may indicate significant periods in the time series. The spectral density function was calculated and plotted for each time series of annual values.

Autocorrelation and spectral density analyses were conducted on records from 1956-1990 at all three sites. Additional autocorrelation and spectral density analyses were conducted on the longest available records at JER and SRER including 1 record from 1915-1990, 2 records from 1918-1991, 5 records from 1926-1990 and 4 records from 1927-1990 at JER (table 3), and 11 records from 1923-1991 at SRER (table 4).

Results and Discussion

Previous analyses of precipitation data collected on the Walnut Gulch Experimental Watershed have shown that interpretations of linear trends depends on the period of record examined (Nichols and others 1993). The longest time period evaluated was 1956-1990, a 35 year period that included drought years during the 1950's as well as later years of above average precipitation in the 1980's. The 6 records examined revealed significant positive linear trends with time ($P \leq .10$).

As previously reported, spectral density analyses did not reveal any consistently dominant periods in the Walnut Gulch records from 1956-1990. Subsets consisting of records from 1956-1990 were analyzed for the 12 longest records available from the JER, and for the 11 longest available records from the SRER. In contrast to results of the Walnut Gulch analysis, there is a suggestion of a 3 year cycle in the 1956-1990 records from both the JER and the SRER.

Because the 1956-1990 records are comparatively short, the analyses have been extended to the JER and SRER precipitation records that are available for 76 and 69 years respectively. The analyses of the long term JER and SRER records are described in the following sections.

Table 3—Summary of spectral density analysis of long record JER raingauges.

Gauge	Period of record	Apparent periodicity (years)	
		Raw data	Without linear trend
Headquarters	1915-1990	76,38,3	
West Well	1918-1991	18,15,3	
Red Lake	1918-1991	74,37,6,2	74,37,6,2
Dona Anna	1926-1990	64,16,5,3	64,16,9,3
Middle Well	1926-1990	64,32,3,2	
Road Tank	1926-1990	64,32,13,5,3	
Stuart	1926-1990	64,32,16,21,5	
Yucca	1926-1990	64,16,13,3	
Aristida	1927-1990	64,32,21,4,3	
Brown Tank	1927-1990	64,32,3	
New Well	1927-1990	64,32,9,3	
Rabbit	1927-1990	64,32,3	64,32,3

Table 4—Summary of spectral density analysis of long record SRER raingauges.

Gauge	Period of record	Apparent periodicity (years)	
		Raw data	Without linear trend
Florida	1923-1990	68,34,3,6,	34,6,3,4
Box	1923-1990	68,5,3	5,3
Desert Station	1923-1990	68,5,6	7,6,5,3
Eriopoda	1923-1990	68,5,3	5,3
Forest	1923-1990	23,3	
Huerfano	1923-1990	70,35,5,4	70,35,5,4
Muhlenbergia	1923-1990	68,6,5,3	6,5,3
NW	1923-1990	68,6,5,3	7,6,5,3
Parker	1923-1990	4,3	
Road	1923-1990	68,34,6,5	
Whitehouse	1923-1990	34,6,5,4	

Jornada Experimental Range

Overall 9 of the 25 records evaluated have a positive linear trend with time ($p \leq 0.05$) (table 1). Figure 2 is a plot of annual precipitation recorded at the JER Headquarters raingauge. The linear trend is shown for the entire record as well as for the period from 1915 to 1960. The 1915-1960 decrease is an apparent short term oscillation in a time series that increased over the period from 1915-1990.

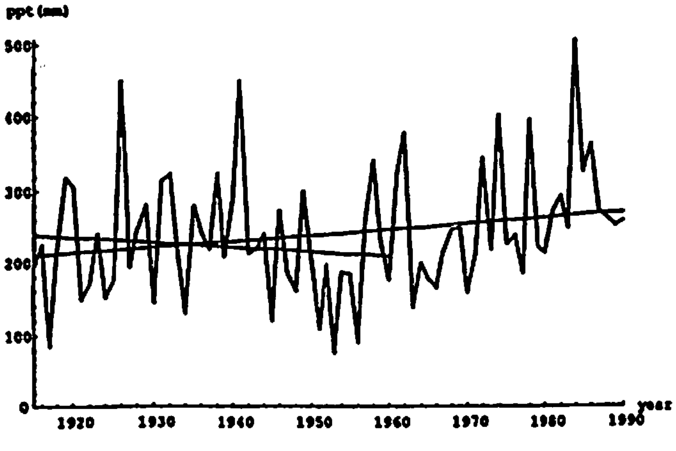


Figure 2—JER Headquarters raingauge showing linear trends from 1915-1990 and 1915-1960.

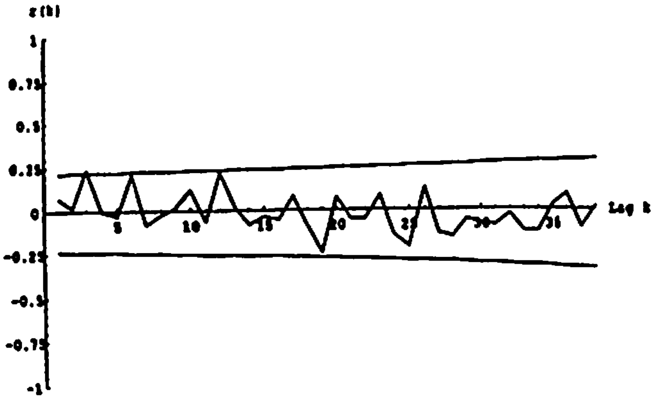


Figure 3—Autocorrelation—JER Headquarters raingauge.

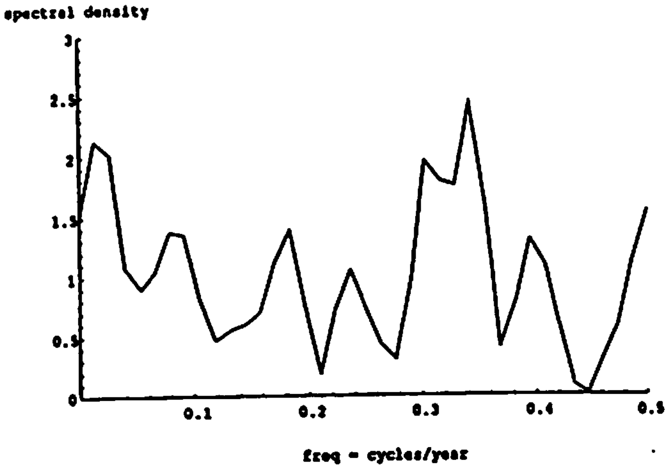


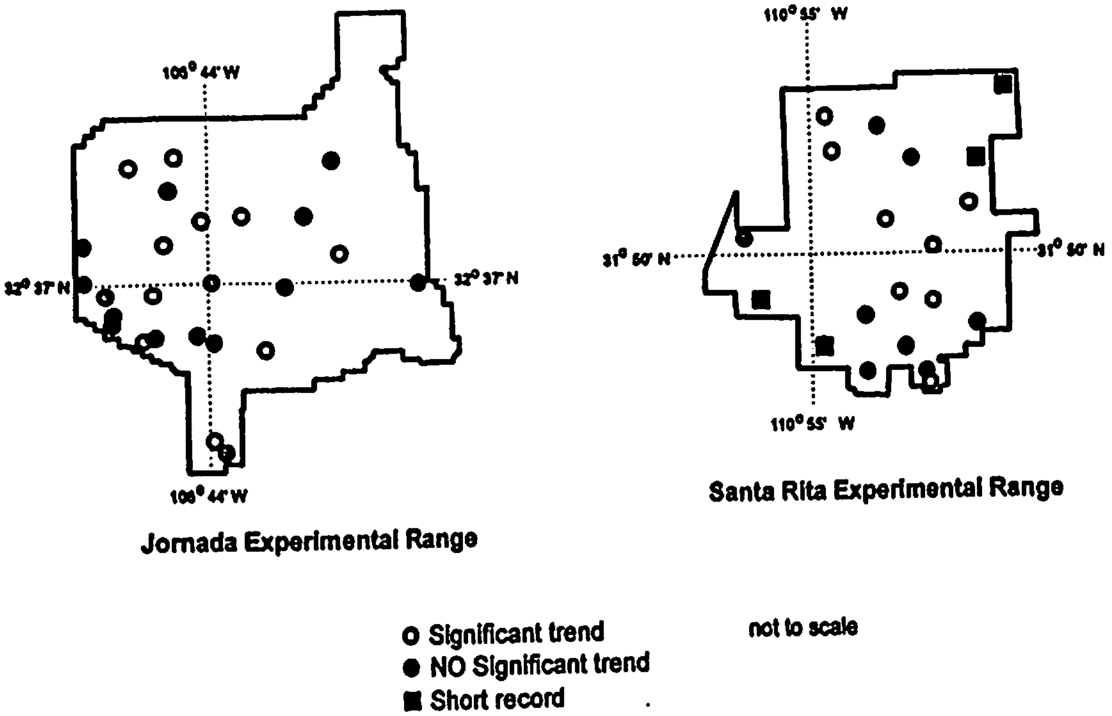
Figure 4—Spectral density—JER Headquarters raingauge.

Figures 3 and 4 show the autocorrelation and spectral density plots for the JER Headquarters raingauge. These plots are representative of the JER annual precipitation records. Although there are significant autocorrelation coefficients and corresponding peaks in the spectral density function, their occurrence is not unexpected in a random time series. However, there is a suggestion of a 3 year period based on the occurrence of a 3 year cycle in 10 of the 12 records examined (table 3).

Santa Rita Experimental Range

Overall 11 of 25 records show a significant positive linear trend with time ($P \leq 0.05$). Of the 11 longest records (1923-1991), 7 have a significant positive linear trend with time (table 2). Autocorrelation and spectral density analyses of the 1923-1991 SRER records suggest a possible 3 year period (table 4).

Preliminary spectral density data for JER and SRER are summarized in tables 3 and 4, respectively. In each table the prominent peaks are listed for each record examined. In addition, records that revealed a significant linear trend



Jornada Experimental Range

Santa Rita Experimental Range

Figure 5—Distribution of raingauges with linear trends—Santa Rita Experimental Range and Jornada Experimental Range.

with time were reanalyzed after being detrended, and prominent peaks are listed for the detrended records. Note that apparent periodicities listed in the tables are calculated as 1/frequency and are rounded to whole years.

The spatial distributions of the 25 JER and 25 SRER raingauges showing significant trends and no significant trends plotted in figure 5 do not reveal any obvious spatial pattern in the distributions.

Conclusions

The particular period of record examined greatly influences interpretations of trends in precipitation records. Therefore, long term historical records are required to determine the effects of drought and periods of above average precipitation on vegetation changes over time, as well as to predict the future response of vegetation to climate change.

Precipitation records from 1956-1990 at Walnut Gulch do not reveal any dominant cycles, however records from the JER and SRER for the same time period suggest a 3 year cycle. A 3 year cycle in annual precipitation was also found during analyses of the longest available records from the JER and the SRER. In addition to total annual precipitation amount, the timing and distribution of precipitation in semiarid regions impact the germination, establishment, rate of growth, length of life and seeding characteristics of grasses and shrubs. Additional analyses are required to evaluate changes in the timing, intensity, or distribution of precipitation that may be reflected in changes in vegetation.

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